Comparison of In-situ Near Infrared Melt Pool Imagery to Optical Microscopy Measurements

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SPIE Thermosense Conference April 3 -7, 2022

Outline

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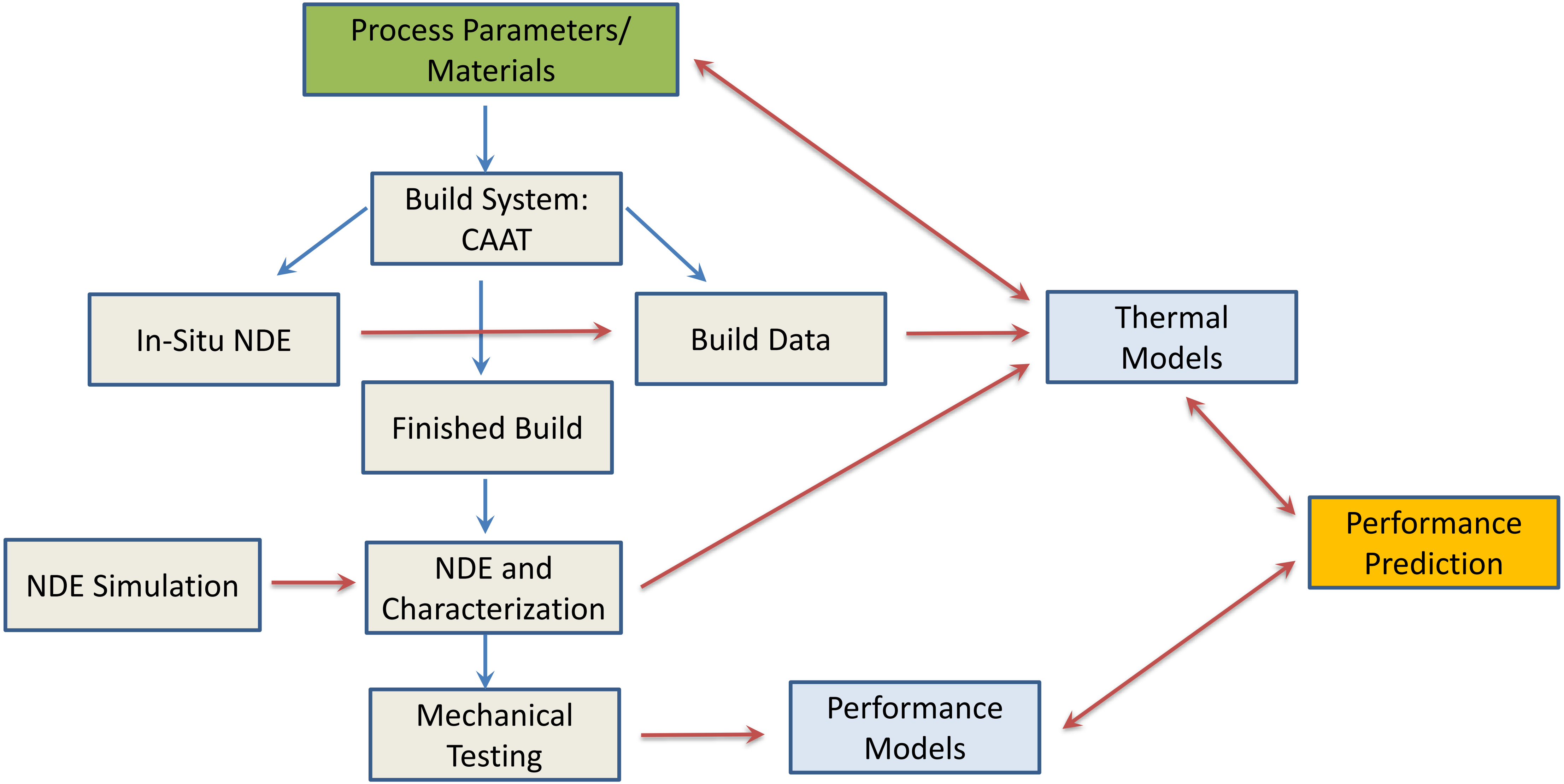
  - Comparison to Optical Microscopy
- Conclusions
- Future Work

NASA Transformational Tools and Technologies Project – Additive Manufacturing (Metals)

Nondestructive Evaluation Sciences Branch



Introduction

Objectives

- Investigate the use of a low cost in-situ near infrared (NIR) sensor for real time measurement of the thermal history for improved additive manufactured builds.

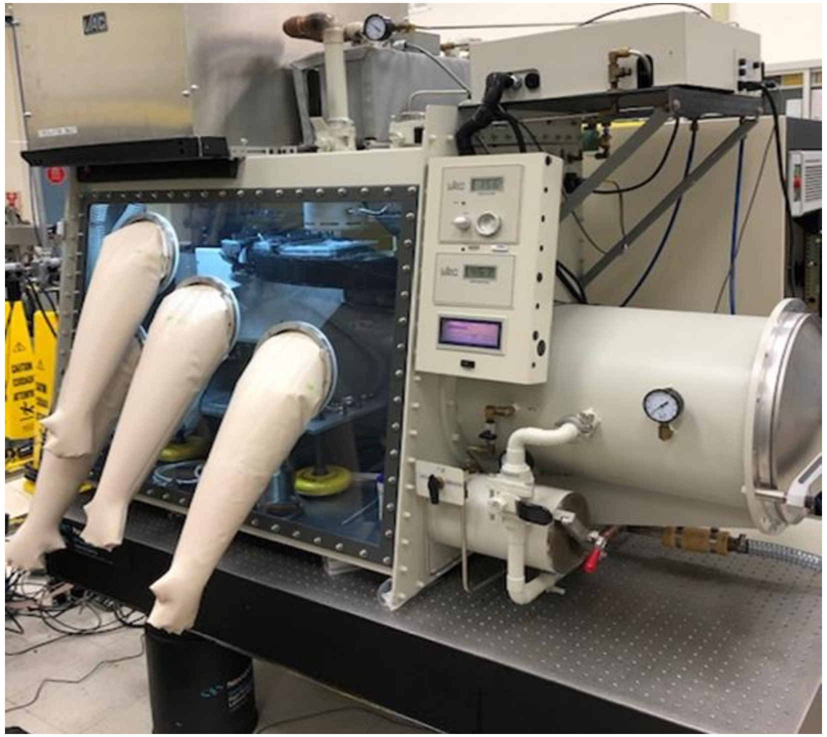
- Calibrate the NIR sensor and investigate the measured melt pool size based on varying process parameters.

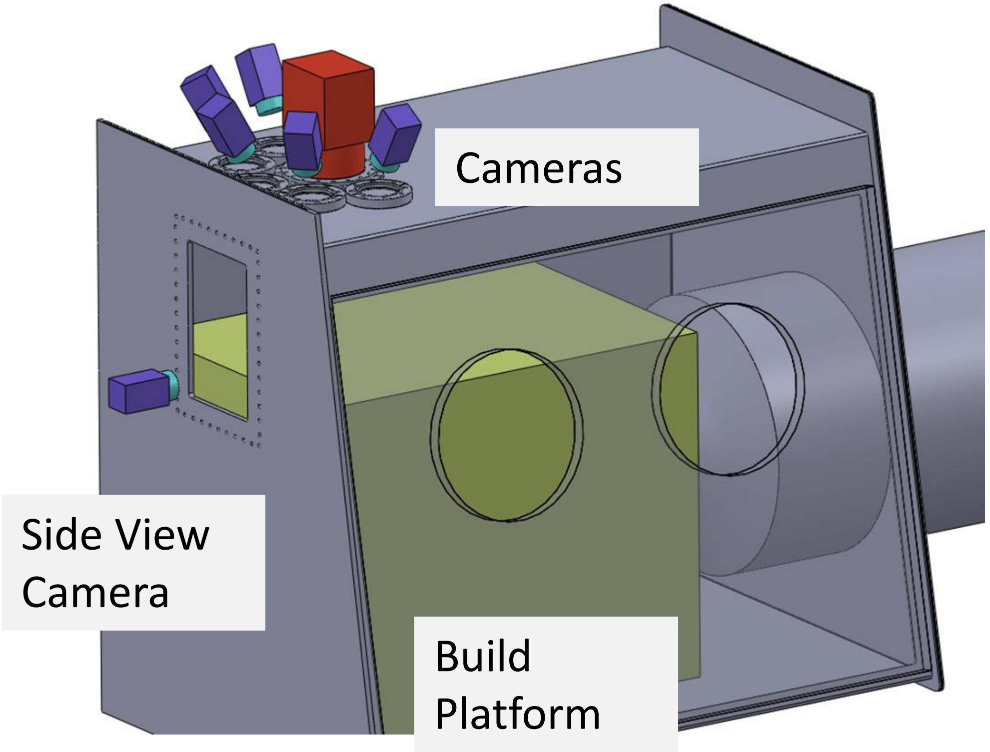
- Compare the melt pool width with microscopy measurements.

Payoffs

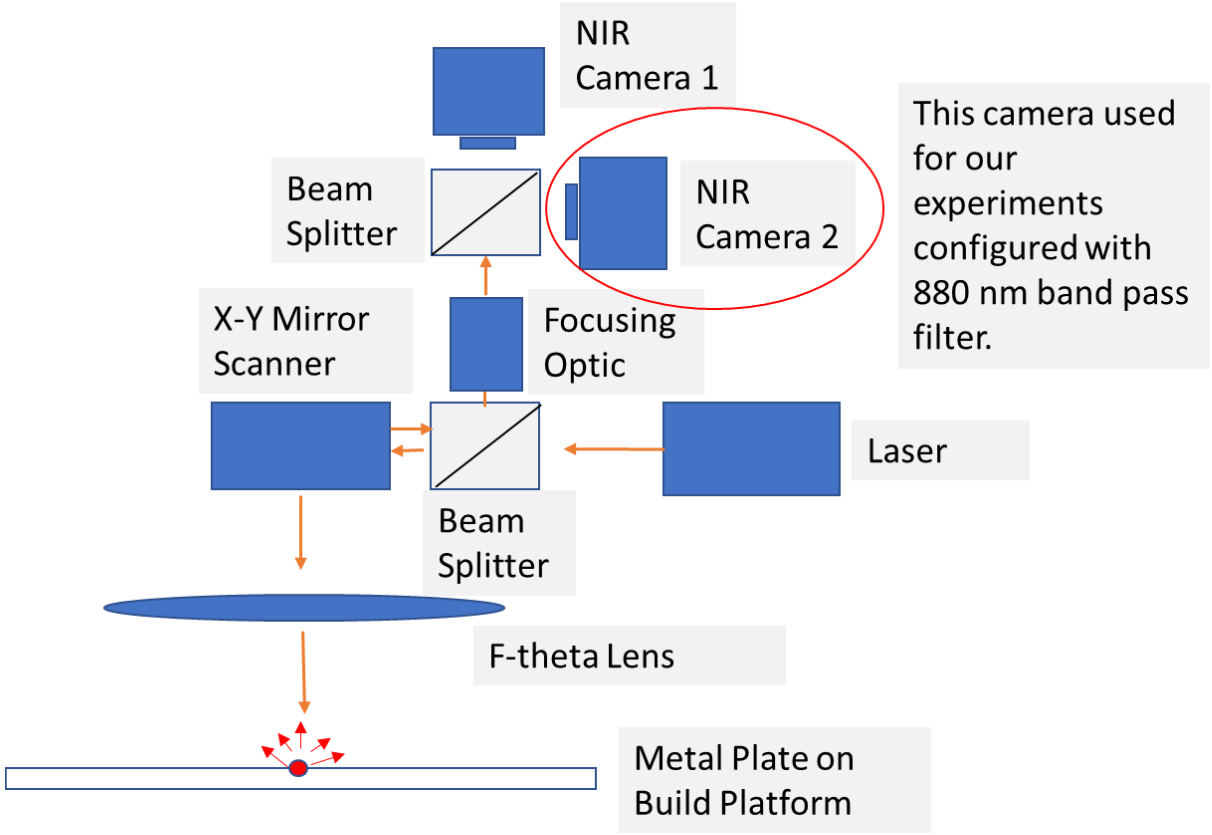
- Additively manufactured parts must be certified for broad application onto aircraft structures. By documenting the thermal history, process parameters for microstructure can be evaluated and real time inspections can be performed during the AM build. These results can be used to validate thermal models and build process parameters.

Configurable Architecture Additive Testbed (CAAT)

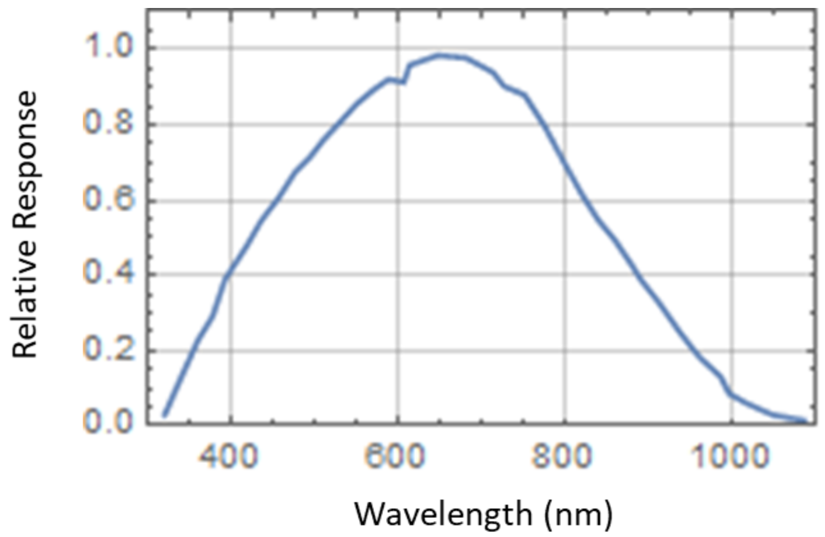




Co-axial NIR Optical Path



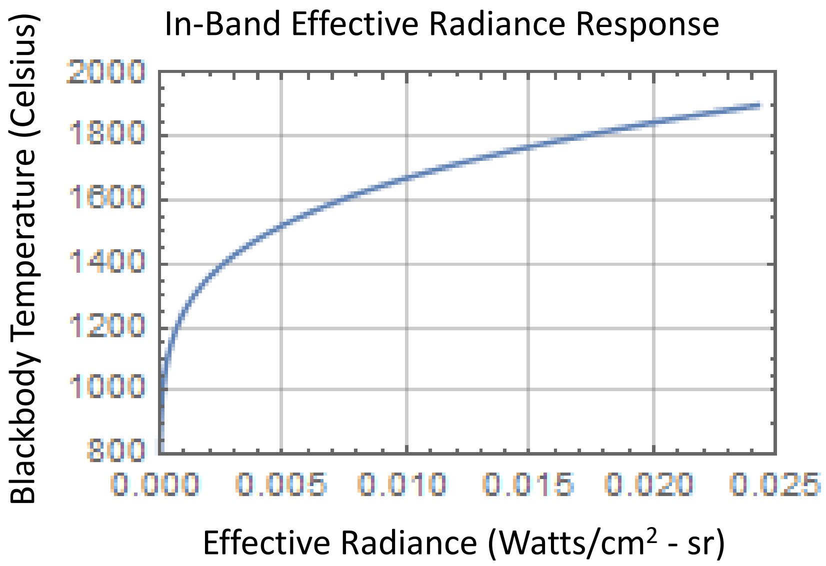
Basler acA640-750um



• NIR camera has 640 x 480 FPA, maximum frame rate = 751 Hz, pixel pitch is 4.8 x 4.8 um, configured with focusing optics and 880 nm narrow bandpass filter (875-884nm), resolution approximately 8.55 microns, ROI for images 144 x144, and provides frame rate of approximately 2,000 Hz.

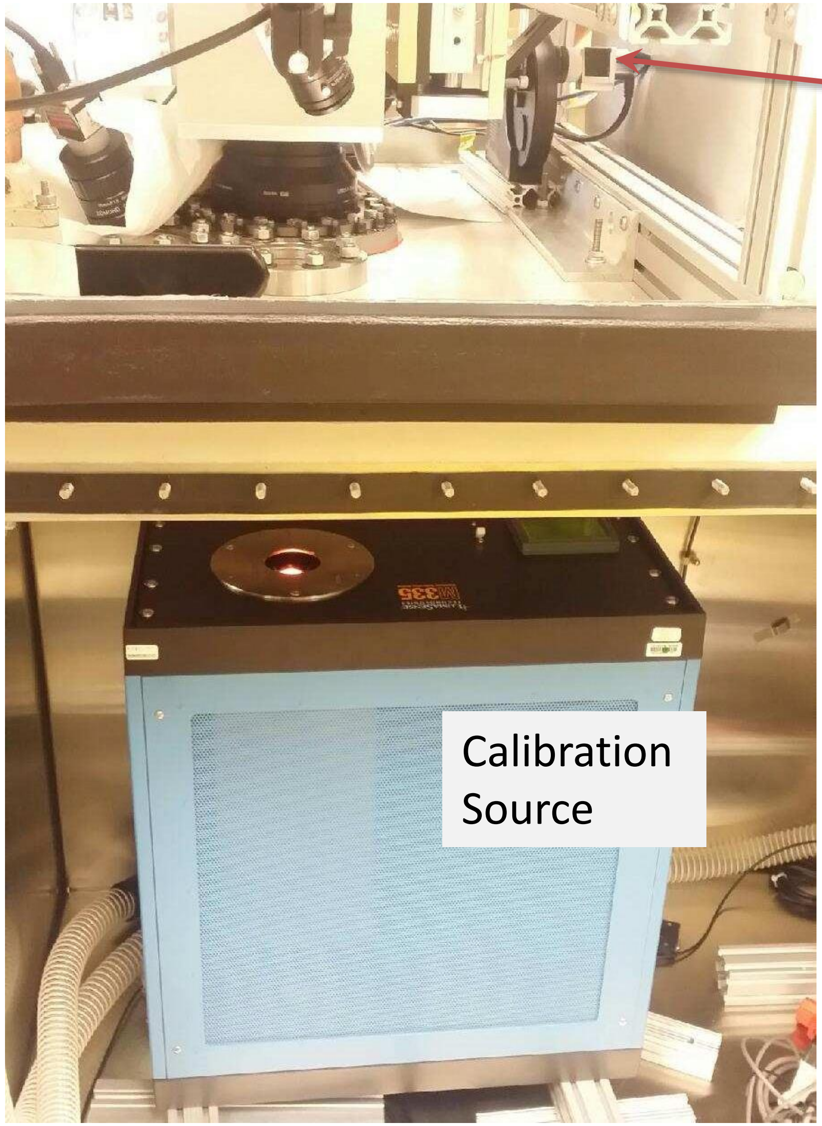
Effective Radiance

$$Radiance = \frac{1}{2}\int_{\lambda_1}^{\lambda_2} \frac{c_1}{\lambda^5\left(e^{\frac{c_2}{\left(\lambda\,(T+273.15)\right)}}-1\right)} * \ sensor(\lambda) * filter(\lambda) * d\lambda \quad \text{where } c_1 = 2 * h * \ c^2 \quad \text{and} \quad c_2 = \frac{h * c}{k}$$



- Spectral band 875 to 884 nm defined by the 880 nm narrow bandpass filter.

Calibration of NIR Camera



- Blackbody radiation source placed within build chamber for direct view.
- Temperatures used were 900, 1000, 1100, 1200, 1300, 1400, and 1500 degrees C.
- Integration times were varied 59, 75, 100, 150, 300, 500, 700, 900, 1200, and 1500 micro-seconds.
- Camera gain was set to 0 db.
- NIR camera was configured with 880 nm band pass filter.
- Camera frame rate approximately 2,000. Hertz with ROI pixel array size of 144x144.

NIR Camera Calibration Results from Blackbody Radiation Source

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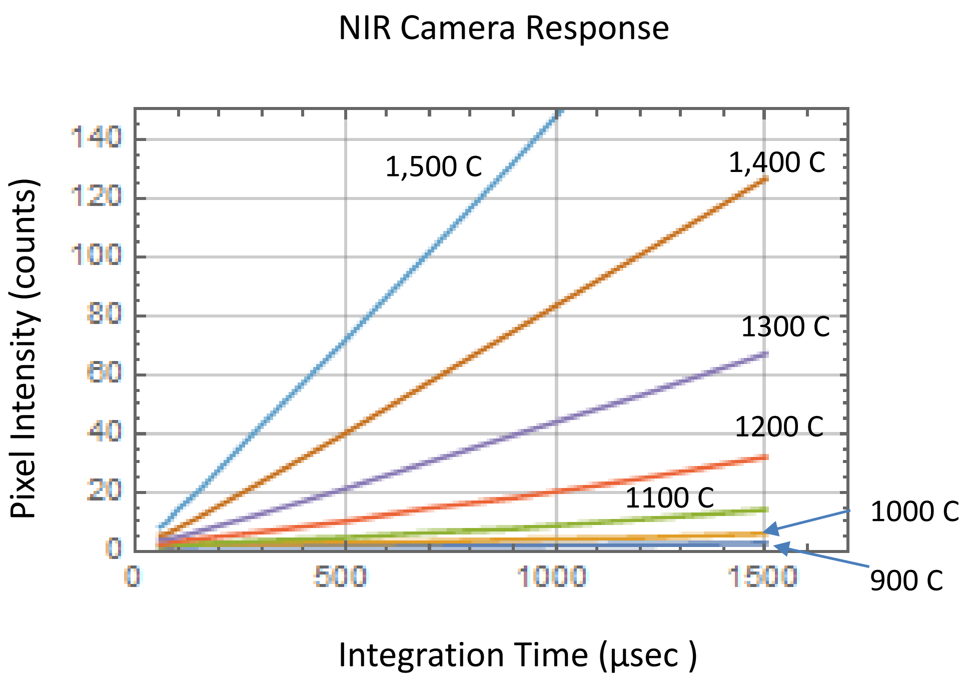

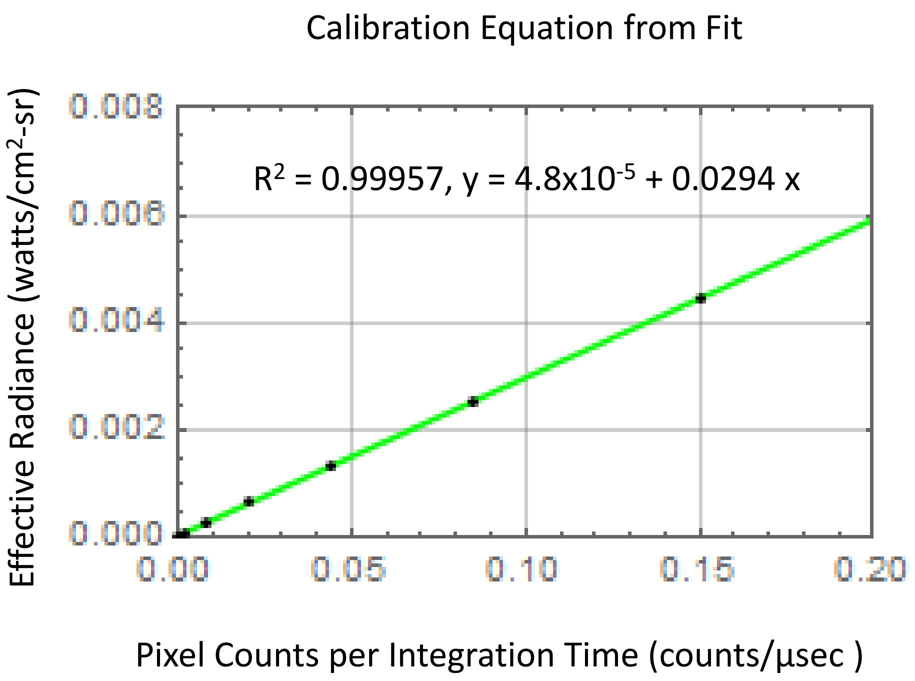

In-situ NIR Melt Pool Imaging Results

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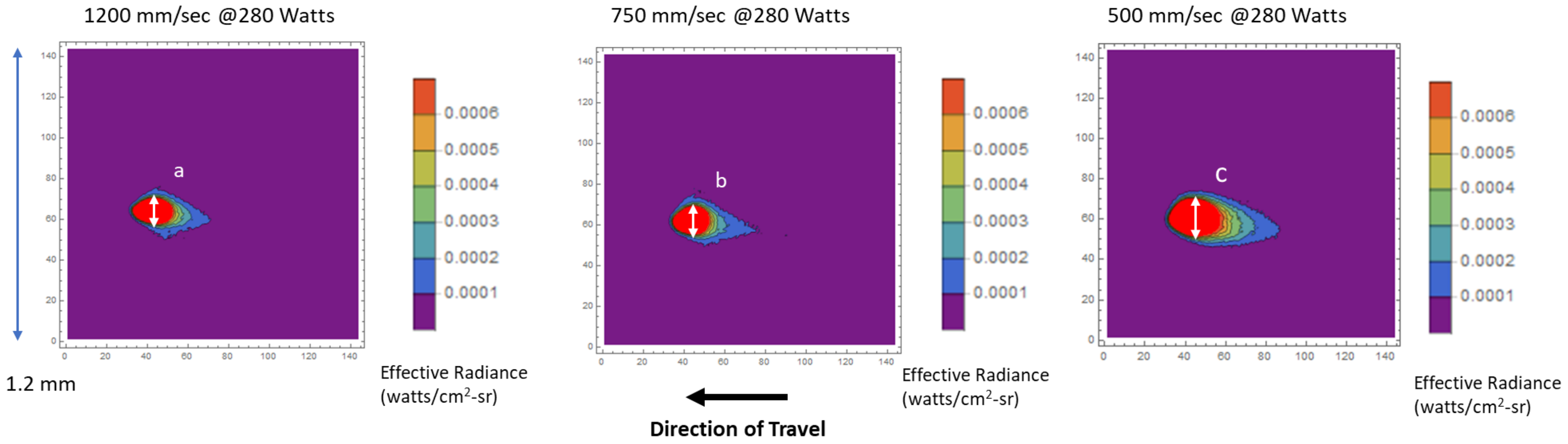
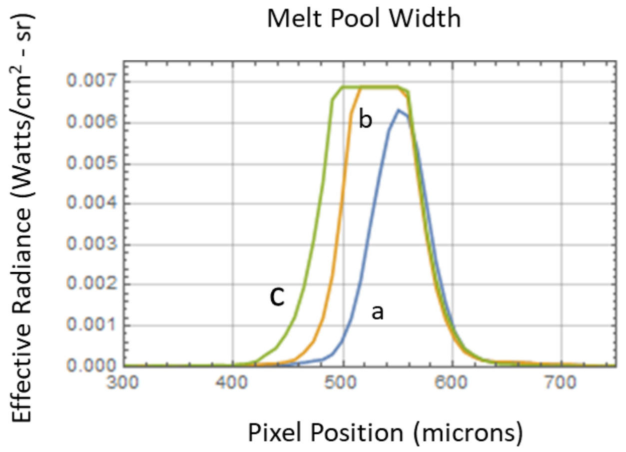


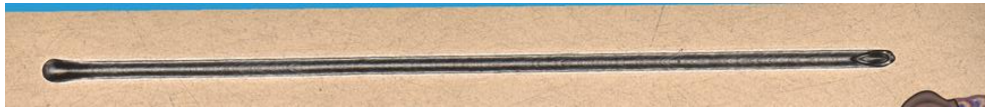


Requirements for Measurement of Melt Pool Width

- Thermal camera pixel resolution – Measured Pixel Resolution Approximately 8.55 microns.
- Solidus temperature value – 1605 Degrees C (Ti-6Al-4V).
- Blurring due to movement of laser beam vs. camera integration time.
- Surface emissivity value (vary with material, surface geometry and temperature).
- Accurate destructive measurements using microscopy.

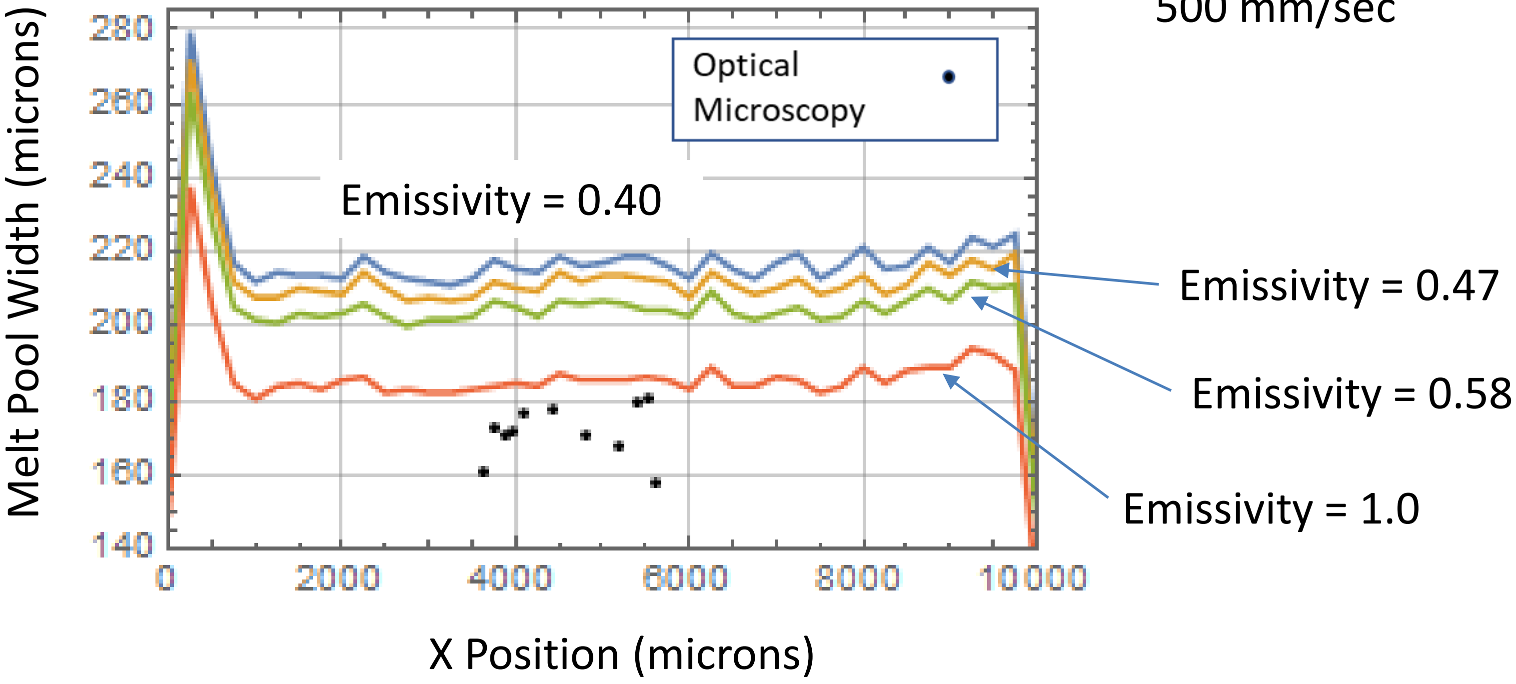
Melt Pool Imagery (Laser Scanning 500 mm/sec) for Various Emissivity Values Compared to Optical Microscopy – Blurring Uncorrected

Top Down Image

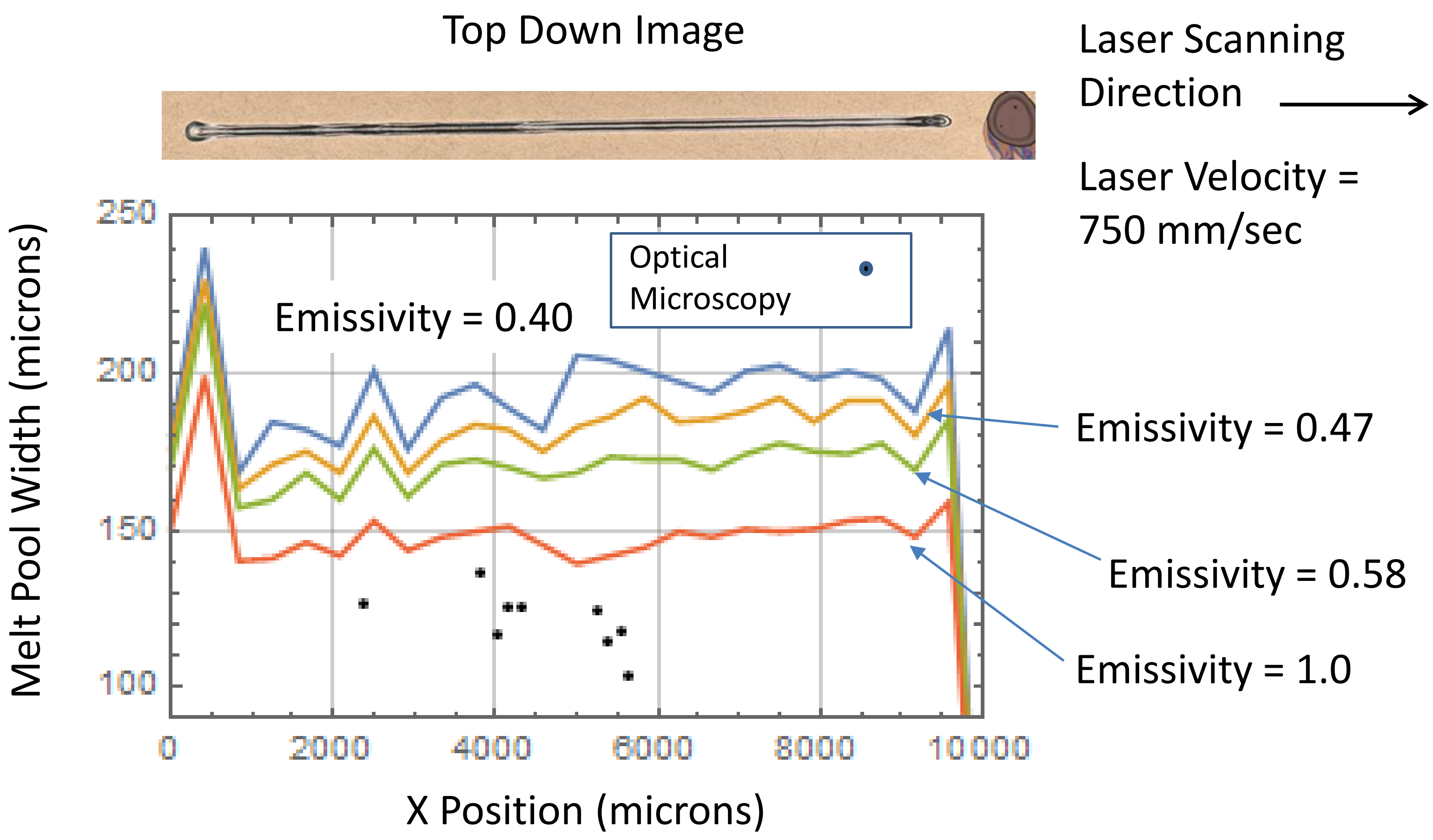


Laser Scanning Direction →

Laser Velocity = 500 mm/sec



Melt Pool Imagery (Laser Scanning 750 mm/sec) for Various Emissivity Values Compared to Optical Microscopy – Blurring Uncorrected



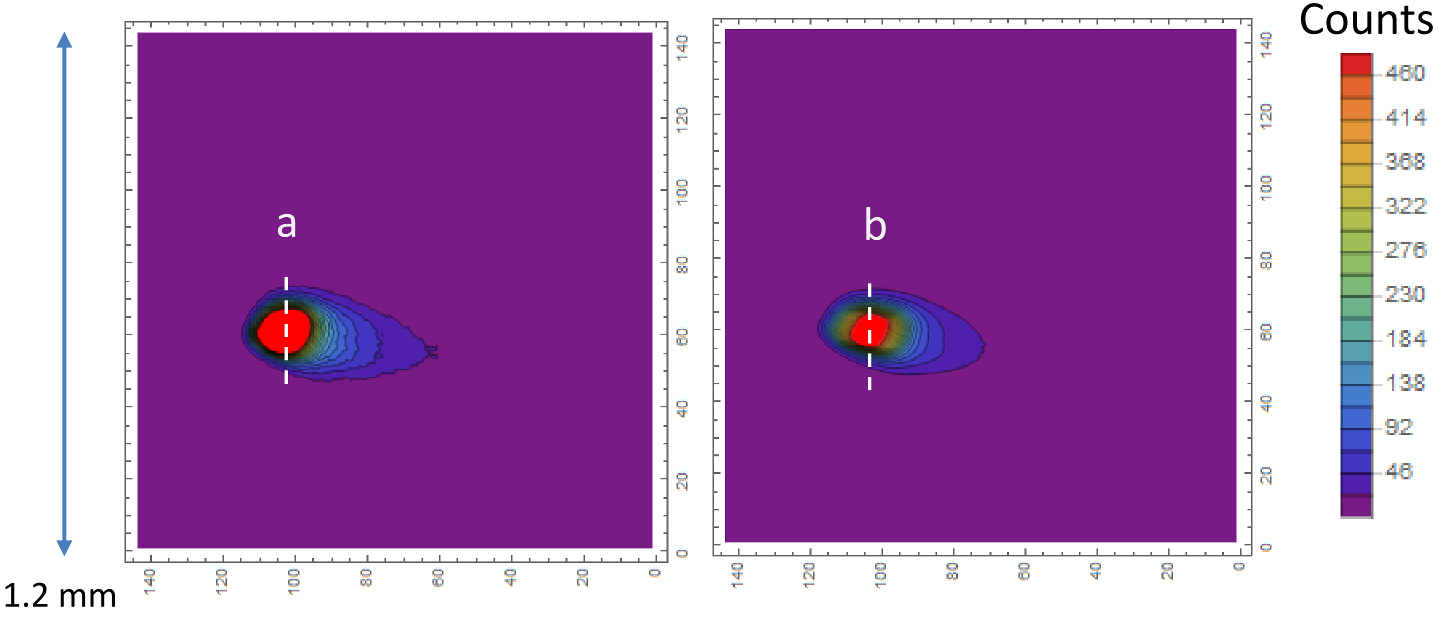
Removal of Blurring using Inverse Filtering

- Laser velocity of 500 and 750 mm/sec combined with camera integration time (200 microseconds) results in ~ 12 pixel and ~ 18 pixel blur respectively.
- Use Weiner inverse filtering technique to remove camera blur.

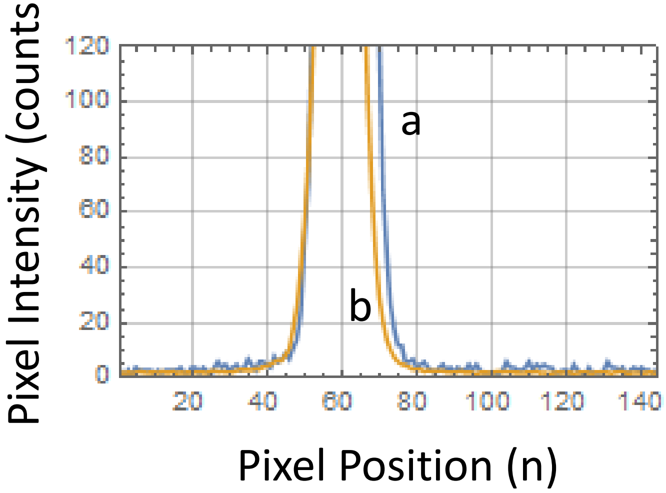
$$W(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 + K(u,v)}$$

$$Deblurred\ Image\ (u,v) = W(u,v) BlurredImage\ (u,v)$$

Blurred   Deblurred   Intensity Counts



Line Plot Across Width

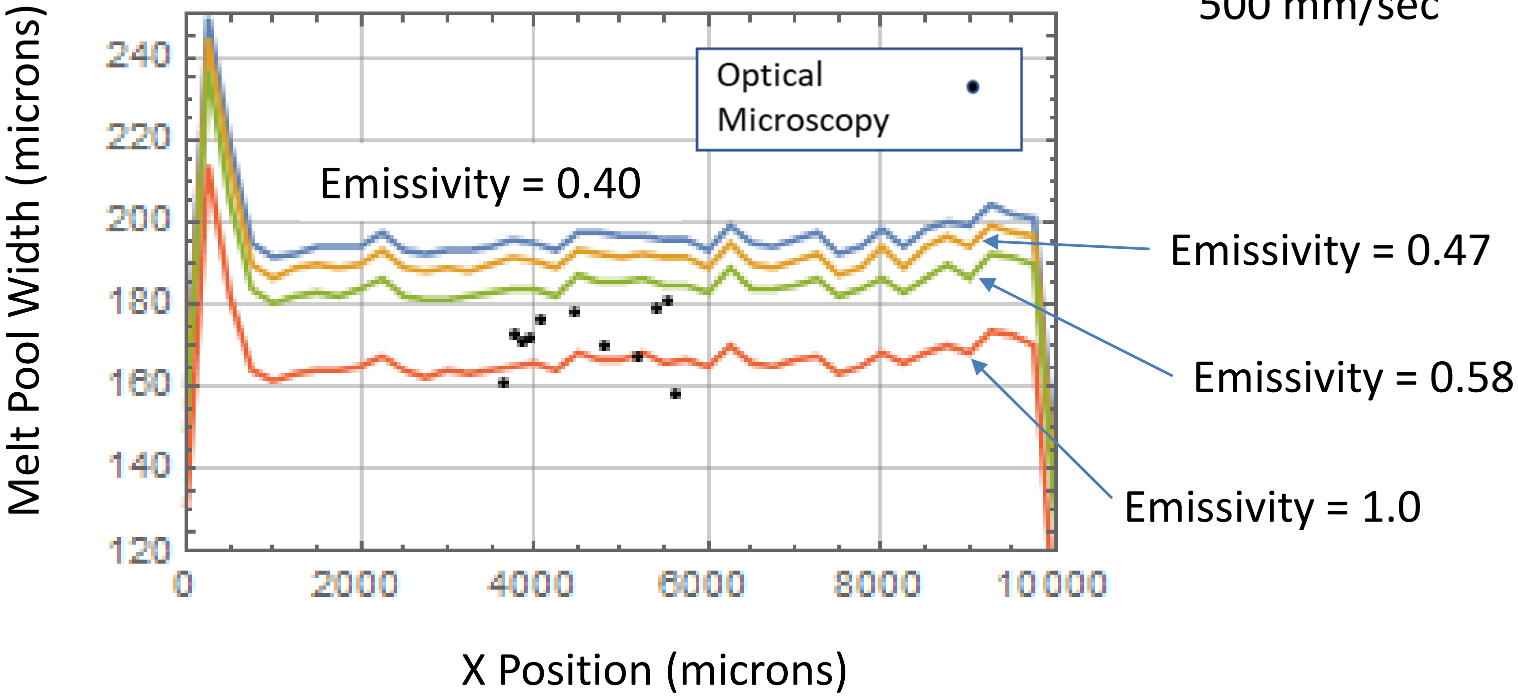


Melt Pool Imagery (Laser Scanning 500 mm/sec) for Various Emissivity Values Compared to Optical Microscopy – Blurring Corrected

Top Down Image

Laser Scanning Direction →

Laser Velocity = 500 mm/sec



Melt Pool Imagery (Laser Scanning 750 mm/sec) for Various Emissivity Values Compared to Optical Microscopy – Blurring Corrected

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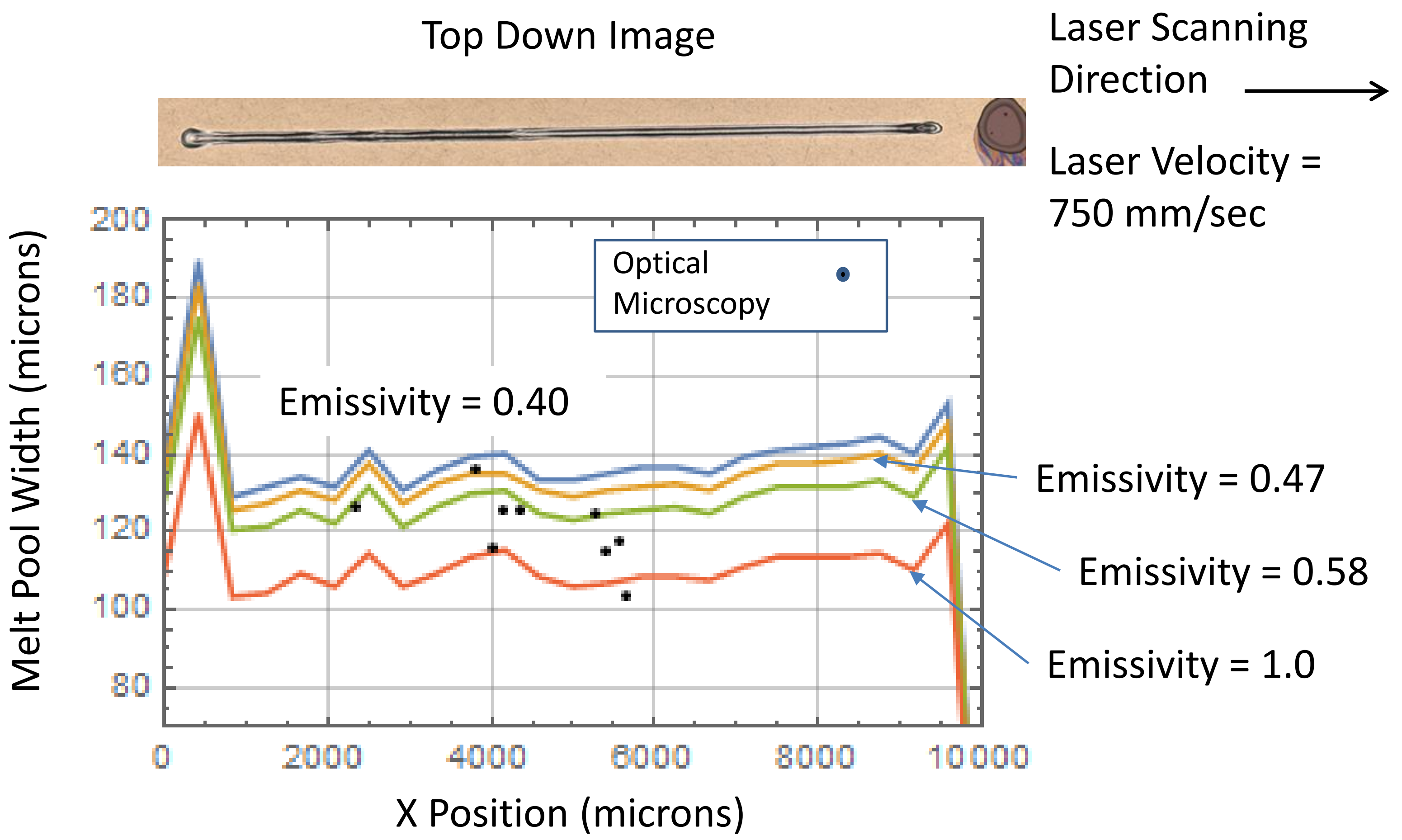
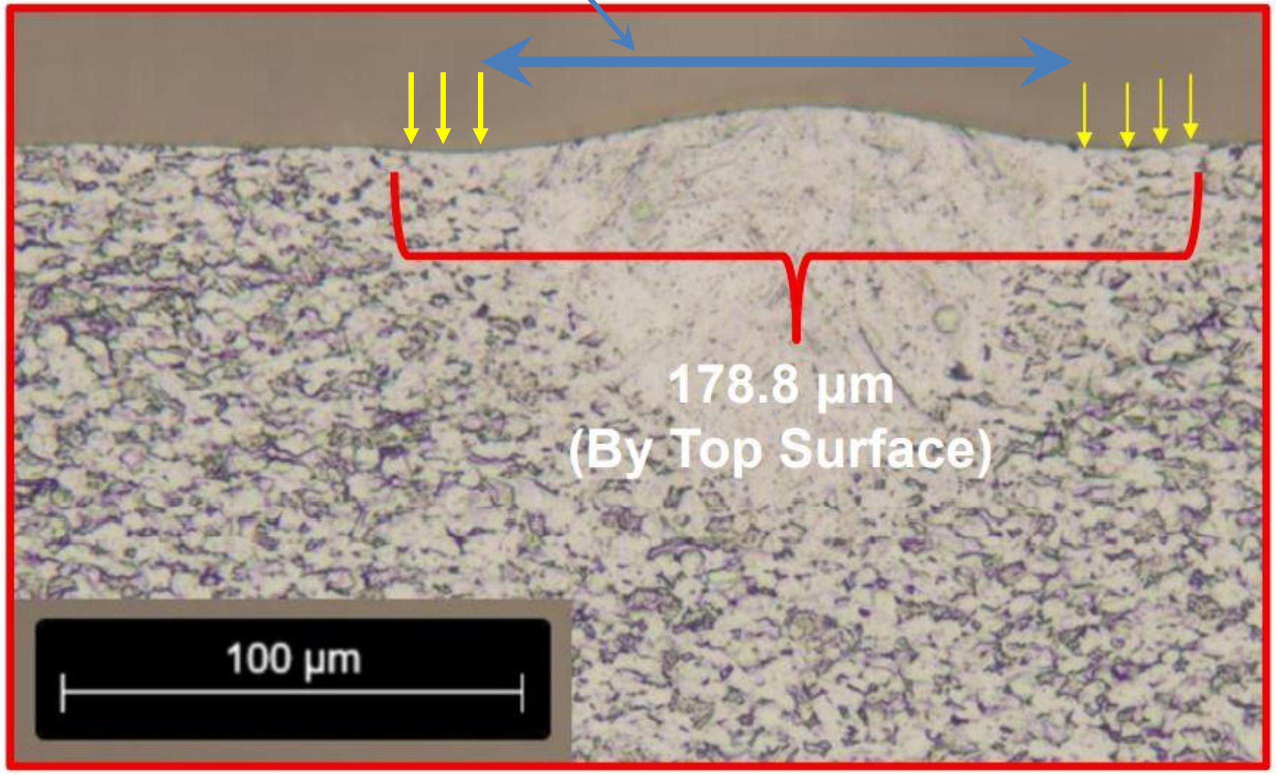


Optical Microscopy Measurement Challenges for Melt Pool Width

Melt Pool Width
by Cross Section



Conclusions

- A low cost NIR camera was calibrated and used to measure the width of the melt pool on a Ti-6Al-4V plate.
- Blurring effects, due to relatively long integration time, was reduced by inverse filtering.
- Optical microscopy measurements were used to compare the NIR melt pool width with marginal agreement. Need to investigate error in optical microscopy measurements to validate NIR melt pool width measurements.

Future Efforts

- Higher speed cameras will be used for improved temporal and spatial imaging.

- Investigate pyrometry imaging techniques for emissivity corrected temperature measurements.

- Comparison of melt pool width measurements to FEM models for given process parameters is desired.

Photron Nova S6